(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 489 461 A1

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
22.12.2004 Bulletin 2004/52

(51) Int Cl.^{7}: G03F 7/20

(21) Application number: 03253694.8

(22) Date of filing: 11.06.2003

(84) Designated Contracting States:
AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HU IE IT LI LU MC NL PT RO SE SI SK TR
Designated Extension States:
AL LT LV MK

(71) Applicant: ASML Netherlands B.V.
5504 DR Veldhoven (NL)

(72) Inventor: The designation of the inventor has not yet been filed

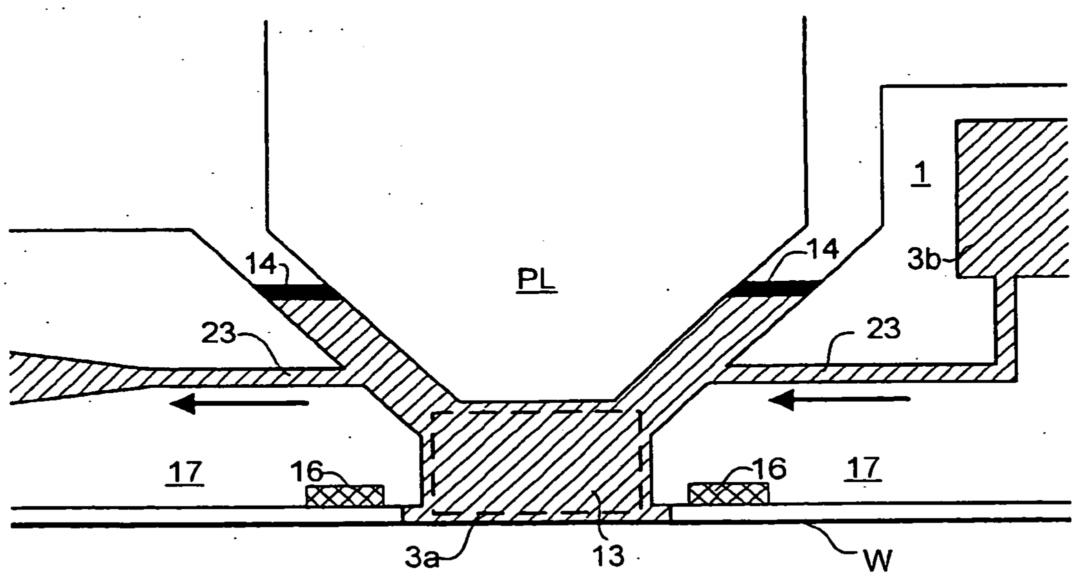
(74) Representative: Leeming, John Gerard
J.A. Kemp & Co.,
14 South Square,
Gray's Inn
London WC1R 5JJ (GB)

Remarks:
Claims 11-15 are deemed to be abandoned due to non-payment of the claims fees (Rule 31 (2) EPC).

(54) Lithographic apparatus and device manufacturing method

(57) A lithographic apparatus and device manufacturing method makes use of a high refractive index liquid confined in a reservoir 13 at least partly filling the imaging field between the final element of the projection lens and the substrate. Bubbles forming in the liquid from dissolved atmospheric gases or from out-gassing from apparatus elements exposed to the liquid are detected and removed so that they do not interfere with exposure and lead to printing defects on the substrate. Detection can be carried out by measuring the frequency dependence of ultrasonic attenuation in the liquid and bubble removal can be implemented by degassing and pressurizing the liquid, isolating the liquid from the atmosphere, using liquids of low surface tension, providing a continuous flow of liquid through the imaging field, and phase shifting ultrasonic standing-wave node patterns.

Fig. 4



EP 1 489 461 A1

Description

[0001] The present invention relates to a lithographic projection apparatus comprising:

- a radiation system for supplying a projection beam of radiation;
- a support structure for supporting patterning means, the patterning means serving to pattern the projection beam according to a desired pattern;
- a substrate table for holding a substrate;
- a projection system for projecting the patterned beam onto a target portion of the substrate; and
- a liquid supply system for at least partly filling a space between the final element of said projection system and said substrate with liquid.

[0002] The term "patterning means" as here employed should be broadly interpreted as referring to means that can be used to endow an incoming radiation beam with a patterned cross-section, corresponding to a pattern that is to be created in a target portion of the substrate; the term "light valve" can also be used in this context. Generally, the said pattern will correspond to a particular functional layer in a device being created in the target portion, such as an integrated circuit or other device (see below). Examples of such patterning means include:

- A mask. The concept of a mask is well known in lithography, and it includes mask types such as binary, alternating phase-shift, and attenuated phase-shift, as well as various hybrid mask types. Placement of such a mask in the radiation beam causes selective transmission (in the case of a transmissive mask) or reflection (in the case of a reflective mask) of the radiation impinging on the mask, according to the pattern on the mask. In the case of a mask, the support structure will generally be a mask table, which ensures that the mask can be held at a desired position in the incoming radiation beam, and that it can be moved relative to the beam if so desired.
- A programmable mirror array. One example of such a device is a matrix-addressable surface having a viscoelastic control layer and a reflective surface. The basic principle behind such an apparatus is that (for example) addressed areas of the reflective surface reflect incident light as diffracted light, whereas unaddressed areas reflect incident light as undiffracted light. Using an appropriate filter, the said undiffracted light can be filtered out of the reflected beam, leaving only the diffracted light behind; in this manner, the beam becomes patterned according to the addressing pattern of the matrix-addressable surface. An alternative embodiment of a programmable mirror array employs a matrix arrangement of tiny mirrors, each of which can be individually tilted about an axis by applying a suitable localized electric field, or by employing piezoelectric actuation means. Once again, the mirrors are matrix-addressable, such that addressed mirrors will reflect an incoming radiation beam in a different direction to unaddressed mirrors; in this manner, the reflected beam is patterned according to the addressing pattern of the matrix-addressable mirrors. The required matrix addressing can be performed using suitable electronic means. In both of the situations described hereabove, the patterning means can comprise one or more programmable mirror arrays. More information on mirror arrays as here referred to can be gleaned, for example, from United States Patents US 5,296,891 and US 5,523,193, and PCT patent applications WO 98/38597 and WO 98/33096, which are incorporated herein by reference. In the case of a programmable mirror array, the said support structure may be embodied as a frame or table, for example, which may be fixed or movable as required.
- A programmable LCD array. An example of such a construction is given in United States Patent US 5,229,872, which is incorporated herein by reference. As above, the support structure in this case may be embodied as a frame or table, for example, which may be fixed or movable as required.

For purposes of simplicity, the rest of this text may, at certain locations, specifically direct itself to examples involving a mask and mask table; however, the general principles discussed in such instances should be seen in the broader context of the patterning means as hereabove set forth.

[0003] Lithographic projection apparatus can be used, for example, in the manufacture of integrated circuits (ICs). In such a case, the patterning means may generate a circuit pattern corresponding to an individual layer of the IC, and this pattern can be imaged onto a target portion (e.g. comprising one or more dies) on a substrate (silicon wafer) that has been coated with a layer of radiation-sensitive material (resist). In general, a single wafer will contain a whole network of adjacent target portions that are successively irradiated via the projection system, one at a time. In current apparatus, employing patterning by a mask on a mask table, a distinction can be made between two different types of machine. In one type of lithographic projection apparatus, each target portion is irradiated by exposing the entire mask pattern onto the target portion in one go; such an apparatus is commonly referred to as a wafer stepper. In an alternative apparatus —commonly referred to as a step-and-scan apparatus — each target portion is irradiated by progressively scanning the mask pattern under the projection beam in a given reference direction (the "scanning" direction) while synchronously scanning the substrate table parallel or anti-parallel to this direction; since, in general, the projection system will have a

magnification factor M (generally < 1), the speed V at which the substrate table is scanned will be a factor M times that at which the mask table is scanned. More information with regard to lithographic devices as here described can be gleaned, for example, from US 6,046,792, incorporated herein by reference.

[0004] In a manufacturing process using a lithographic projection apparatus, a pattern (e.g. in a mask) is imaged onto a substrate that is at least partially covered by a layer of radiation-sensitive material (resist). Prior to this imaging step, the substrate may undergo various procedures, such as priming, resist coating and a soft bake. After exposure, the substrate may be subjected to other procedures, such as a post-exposure bake (PEB), development, a hard bake and measurement/inspection of the imaged features. This array of procedures is used as a basis to pattern an individual layer of a device, e.g. an IC. Such a patterned layer may then undergo various processes such as etching, ion-implantation (doping), metallization, oxidation, chemo-mechanical polishing, etc., all intended to finish off an individual layer. If several layers are required, then the whole procedure, or a variant thereof, will have to be repeated for each new layer. Eventually, an array of devices will be present on the substrate (wafer). These devices are then separated from one another by a technique such as dicing or sawing, whence the individual devices can be mounted on a carrier, connected to pins, etc. Further information regarding such processes can be obtained, for example, from the book "Microchip Fabrication: A Practical Guide to Semiconductor Processing", Third Edition, by Peter van Zant, McGraw Hill Publishing Co., 1997, ISBN 0-07-067250-4, incorporated herein by reference.

[0005] For the sake of simplicity, the projection system may hereinafter be referred to as the "lens"; however, this term should be broadly interpreted as encompassing various types of projection system, including refractive optics, reflective optics, and catadioptric systems, for example. The radiation system may also include components operating according to any of these design types for directing, shaping or controlling the projection beam of radiation, and such components may also be referred to below, collectively or singularly, as a "lens". Further, the lithographic apparatus may be of a type having two or more substrate tables (and/or two or more mask tables). In such "multiple stage" devices the additional tables may be used in parallel, or preparatory steps may be carried out on one or more tables while one or more other tables are being used for exposures. Dual stage lithographic apparatus are described, for example, in US 5,969,441 and WO 98/40791, incorporated herein by reference.

[0006] It has been proposed to immerse the substrate in a lithographic projection apparatus in a liquid having a relatively high refractive index, e.g. water, so as to fill the space between the final element of the projection lens and the substrate. The point of this is to enable imaging of smaller features since the exposure radiation will have a shorter wavelength in the liquid. (The effect of the liquid may also be regarded as increasing the effective NA of the system.)

[0007] One of the solutions proposed is to submerse the substrate or substrate and substrate table in a bath of liquid (see for example US 4,509,852, hereby incorporated in its entirety by reference). In this solution, there is a large body of liquid that must be accelerated during a scanning exposure. This may require additional or more powerful motors and may cause turbulence in the liquid leading to possible undesirable and unpredictable effects.

[0008] Another of the solutions proposed is for a liquid supply system to provide liquid in a localized area between the final element of the projection system and the substrate (the substrate generally has a larger surface area than the final element of the projection system). One way that has been proposed to arrange for this is disclosed in WO 99/49504, hereby incorporated in its entirety by reference. As illustrated in Figures 2 and 3, liquid is supplied by at least one inlet IN onto the substrate, preferably along the direction of movement of the substrate relative to the final element, and is removed by at least one outlet OUT after having passed under the projection system. That is, as the substrate is scanned beneath the element in a -X direction, liquid is supplied at the +X side of the element and taken up at the -X side. Figure 2 shows the arrangement schematically in which liquid is supplied via inlet IN and is taken up on the other side of the element by outlet OUT which is connected to a low pressure source. In the illustration of Figure 2 the liquid is supplied along the direction of movement of the substrate relative to the final element, though this does not need to be the case. Various orientations and numbers of inlets and outlets positioned around the final element are possible, one example is illustrated in Figure 3 in which four sets of an inlet with an outlet on either side are provided in a regular pattern around the final element.

[0009] Another solution that has been proposed is to provide the liquid supply system with a seal member which extends along at least a part of a boundary of the space between the final element of the projection system and the substrate table. The seal member is substantially stationary relative to the projection system in the XY plane and a seal is formed between the seal member and the surface of the substrate. Preferably the seal is a contactless seal such as a gas seal (see, for example, European patent application 03252955.4 hereby incorporated in its entirety by reference).

[0010] Unexpected disadvantages emerge from this new technology when compared with systems that do not have liquid in the exposure radiation path. In particular, despite the improved imaging resolution, the liquid tends to degrade the image quality in other respects.

[0011] It is an obj ect of the present invention to improve the imaging performance of an apparatus having

a liquid filling a space between the final element of the projection system and the substrate.

[0012] This and other objects are achieved according to the invention in a lithographic apparatus as specified in the opening paragraph, characterized in that the liquid supply system comprises bubble reduction means.

[0013] It has been realized that an important source of image degradation is the scattering of imaging radiation from bubbles in the liquid. By reducing the size and concentration of these bubbles it is possible to reduce this scattering and the associated distortion of the image reaching the substrate, thereby reducing the frequency and magnitude of defects in the printed pattern on the substrate. Bubbles typically form when dissolved gases from the atmosphere come out of solution due to a disturbance of some kind, or from out-gassing elements of the lithographic apparatus, such as a photosensitive layer on the substrate. Bubbles thus formed may vary greatly in number density and size distribution depending on the liquid, gases and disturbances involved. Very fine bubbles tend to cause particular problems as they are both difficult to detect and hard to remove using standard methods and yet still influence the image formed on the substrate. For use in the context of a typical lithographic apparatus, for example, bubbles continue to degrade performance down to around 10 nm in diameter.

[0014] The bubble reduction means may comprise bubble detection means. It is preferred that the bubble detection means comprise one or more ultrasonic transducers. These transducers may emit ultrasonic waves and receive ultrasonic waves that are influenced by the presence of bubbles in the liquid within which they propagate. The information yielded by the ultrasonic transducers may include information about the distribution of bubble sizes as well as their number density.

[0015] The ultrasonic transducers may also measure the ultrasonic attenuation as a function of frequency. The advantage of this approach is that it is possible to detect bubbles with dimensions very much smaller than the wavelength of the ultrasonic waves. Using only the amplitude of the signal would restrict this measurement method to bubbles of the same size or greater than the wavelength of the ultrasonic waves.

[0016] A further feature is that the bubble reduction means comprises a bubble removal means.

[0017] The bubble removal means may comprise a degassing device, the degassing device comprising an isolation chamber, wherein a space above liquid in the isolation chamber is maintained at a pressure below atmospheric pressure encouraging previously dissolved gases to come out of solution and be pumped away. This degassing process dramatically reduces the occurrence of bubbles due to dissolved atmospheric gases coming out of solution. Following the degassing process, the liquid is preferably kept as isolated as possible from the normal atmosphere.

[0018] A further feature is that the bubble removal means provide a continuous flow of liquid over the final element of the projection system and the substrate in order to transport bubbles out of the imaging field. This step is particularly effective for removing gases originating from out-gassing elements of the lithographic apparatus.

[0019] Additionally, the bubble reduction means may pressurize the liquid above atmospheric pressure to minimize the size of bubbles and encourage bubble-forming gases to dissolve into the liquid.

[0020] The composition of the liquid may also be chosen to have a lower surface tension than water. This reduces the tendency of bubbles to stick to the substrate where they may be particularly damaging to the image and where they tend to be resistant to removal measures.

[0021] The bubble reduction means may treat the liquid before it is introduced into the space between the final element of the projection system and the substrate. An advantage of this approach is improved space considerations and liberty of design. These factors make it easier to treat liquid in bulk for use in a plurality of lithographic apparatuses or for use in a circulatory system or where the liquid is to be replaced on a frequent basis. After treatment, the liquid may be protected from atmospheric gases by being kept under vacuum or by being exposed only to a gas, such as nitrogen, argon or helium, which does not easily dissolve into the liquid.

[0022] The ultrasonic transducers of the bubble detection means may be arranged in a pulse-echo arrangement wherein the same transducer emits waves and, after reflection from a boundary, receives waves attenuated by propagation through the liquid. An advantage of this arrangement is that fewer transducers are required and it is easier to arrange a relatively long signal path through the liquid.

[0023] Alternatively, the bubble detection means may comprise two spatially separated ultrasonic transducers, the first arranged to transmit, and the second to receive waves. An advantage of this arrangement is that the signal received at the receiving transducer may be easier to interpret and may suffer less from anomalous signal loss caused, for example, by non-specular reflection from the boundary.

[0024] Optionally, the bubble removal means may include two spatially separated ultrasonic transducers, arranged to produce ultrasonic standing-wave patterns within the liquid that trap bubbles within the nodal regions. The bubble removal means is arranged to displace said bubbles through the use of phase adjusting means linked with the transducers, the phase adjusting means causing spatial shift of the nodal regions and of bubbles trapped within them. This process may be used to transport bubbles completely to one side of a liquid reservoir where they may be isolated and removed from the system.

[0025] According to a further aspect of the invention there is provided a device manufacturing method com-

prising the steps of:

- providing a substrate that is at least partially covered by a layer of radiation-sensitive material;
- providing a projection beam of radiation using a radiation system;
- using patterning means to endow the projection beam with a pattern in its cross-section;
- projecting the patterned beam of radiation onto a target portion of the layer of radiation-sensitive material,
- providing a liquid supply system for filling the space between the final element of the projection system and said substrate with liquid,
- characterized by the step of reducing bubbles in said liquid supply system.

[0026] Although specific reference may be made in this text to the use of the apparatus according to the invention in the manufacture of ICs, it should be explicitly understood that such an apparatus has many other possible applications. For example, it may be employed in the manufacture of integrated optical systems, guidance and detection patterns for magnetic domain memories. liquid-crystal display panels, thin-film magnetic heads, etc. The skilled artisan will appreciate that, in the context of such alternative applications, any use of the terms "reticle", "wafer" or "die" in this text should be considered as being replaced by the more general terms "mask", "substrate" and "target portion", respectively.

[0027] In the present document, the terms "radiation" and "beam" are used to encompass all types of electromagnetic radiation, including ultraviolet radiation (e.g. with a wavelength of 365, 248, 193, 157 or 126 nm).

[0028] Embodiments of the invention will now be described, by way of example only, with reference to the accompanying schematic drawings in which:

Figure 1 depicts a lithographic projection apparatus according to an embodiment of the invention;
Figure 2 depicts a liquid supply system for supplying liquid to the area around the final element of the projection system according to an embodiment of the invention;
Figure 3 depicts the arrangement of inlets and outlets of the liquid supply system of Figure 2 around the final element of the projection system according to an embodiment of the invention;
Figure 4 depicts a liquid supply system with bubble reduction means according to an embodiment of the invention;
Figure 5 depicts two possible arrangements of ultrasonic transducers in a bubble detection means according to two embodiments of the invention;
Figure 6 depicts an arrangement of ultrasonic transducers and standing waves in a bubble removal means according to an embodiment of the invention;
Figure 7 depicts a degassing device according to an embodiment of the invention.
Figure 8 depicts a liquid pressurization device according to an embodiment of the invention.

[0029] In the Figures, corresponding reference symbols indicate corresponding parts.

Embodiment 1

[0030] Figure 1 schematically depicts a lithographic projection apparatus according to a particular embodiment of the invention. The apparatus comprises:

- a radiation system Ex, IL, for supplying a projection beam PB of radiation (*e.g.* DUV radiation), which in this particular case also comprises a radiation source LA;
- a first object table (mask table) MT provided with a mask holder for holding a mask MA (*e.g.* a reticle), and connected to first positioning means for accurately positioning the mask with respect to item PL;
- a second object table (substrate table) WT provided with a substrate holder for holding a substrate W (*e.g.* a resist-coated silicon wafer), and connected to second positioning means for accurately positioning the substrate with respect to item PL;
- a projection system ("lens") PL (*e.g.* a refractive lens system) for imaging an irradiated portion of the mask MA onto a target portion C (*e.g.* comprising one or more dies) of the substrate W.

As here depicted, the apparatus is of a transmissive type (*e.g.* has a transmissive mask). However, in general, it may also be of a reflective type, for example (*e.g.* with a reflective mask). Alternatively, the apparatus may employ another kind of patterning means, such as a programmable mirror array of a type as referred to above.

[0031] The source LA (*e.g.* an excimer laser) produces a beam of radiation. This beam is fed into an illumination system (illuminator) IL, either directly or after having traversed conditioning means, such as a beam expander Ex, for example. The illuminator IL may comprise adjusting means AM for setting the outer and/or inner radial extent (commonly referred to as σ-outer and σ-inner, respectively) of the intensity distribution in the beam. In addition, it will generally comprise various other components, such as an integrator IN and a condenser CO. In this way, the beam PB impinging on the mask MA has a desired uniformity and intensity distribution in its cross-section.

[0032] It should be noted with regard to Figure 1 that the source LA may be within the housing of the lithographic projection apparatus (as is often the case when the source LA is a mercury lamp, for example), but that it may also be remote from the lithographic projection apparatus, the radiation beam which it produces being led into the apparatus (e.g. with the aid of suitable di-

recting mirrors); this latter scenario is often the case when the source LA is an excimer laser. The current invention and Claims encompass both of these scenarios.

[0033] The beam PB subsequently intercepts the mask MA, which is held on a mask table MT. Having traversed the mask MA, the beam PB passes through the lens PL, which focuses the beam PB onto a target portion C of the substrate W. With the aid of the second positioning means (and interferometric measuring means IF), the substrate table WT can be moved accurately, *e.g.* so as to position different target portions C in the path of the beam PB. Similarly, the first positioning means can be used to accurately position the mask MA with respect to the path of the beam PB, *e.g.* after mechanical retrieval of the mask MA from a mask library, or during a scan. In general, movement of the object tables MT, WT will be realized with the aid of a long-stroke module (course positioning) and a short-stroke module (fine positioning), which are not explicitly depicted in Figure 1. However, in the case of a wafer stepper (as opposed to a step-and-scan apparatus) the mask table MT may just be connected to a short stroke actuator, or may be fixed.

[0034] The depicted apparatus can be used in two different modes:

1. In step mode, the mask table MT is kept essentially stationary, and an entire mask image is projected in one go (*i.e.* a single "flash") onto a target portion C. The substrate table WT is then shifted in the x and/or y directions so that a different target portion C can be irradiated by the beam PB;
2. In scan mode, essentially the same scenario applies, except that a given target portion C is not exposed in a single "flash". Instead, the mask table MT is movable in a given direction (the so-called "scan direction", *e.g.* the y direction) with a speed v, so that the projection beam PB is caused to scan over a mask image; concurrently, the substrate table WT is simultaneously moved in the same or opposite direction at a speed $V= Mv$, in which M is the magnification of the lens PL (typically, M = 1/4 or 1/5). In this manner, a relatively large target portion C can be exposed, without having to compromise on resolution.

[0035] Figures 2 and 3 depict a liquid supply system according to an embodiment of the invention and have been described above. Other liquid supply systems may be employed according to embodiments of the invention including, without limitation, a bath of liquid and seal member as described above.

[0036] Figure 4 shows the liquid supply system 1 and the bubble reduction means 3a/3b according to an embodiment of the invention. The bubble reduction means 3a/3b may be located underneath the projection lens 3 a, or exterior to the imaging axis 3b. The liquid supply system 1 supplies liquid to a reservoir 13 between the projection lens PL and the wafer W. The liquid is preferably chosen to have a refractive index substantially greater than one meaning that the wavelength of the projection beam is shorter in the liquid than in air or a vacuum, allowing smaller features to be resolved. It is well known that the resolution of a projection system is determined, *inter alia,* by the wavelength of the projection beam and the numerical aperture of the system. The presence of the liquid may also be regarded as increasing the effective numerical aperture.

[0037] If the liquid has been exposed to the atmosphere, some atmospheric gases may be dissolved in the liquid. Disturbances of the fluid (in any way) may give rise to the formation of bubbles, which, depending on the liquid, gases and disturbances involved, may be very fine. Fine bubbles, down to around 10 nm in diameter, are very difficult to detect using standard methods but still interfere with the imaging performance of the exposure radiation, distorting the image and leading to printing defects on the wafer. Bubbles may also enter the reservoir 13 via out-gassing from elements within the lithographic apparatus such as the photosensitive layer on the substrate W when it is exposed.

[0038] The reservoir is bounded at least in part by a seal member 17 positioned below and surrounding the final element of the projection lens PL. The seal member 17 extends a little above the final element of the projection lens PL and the liquid level rises above the bottom end of the final element of the projection lens PL. The seal member 17 has an inner periphery that at the upper end closely conforms to the step of the projection system or the final element thereof and may, *e.g.*, be round. At the bottom, the inner periphery closely conforms to the shape of the image field, *e.g.* rectangular but may be any shape.

[0039] Between the seal member 17 and the wafer W, the liquid can be confined to the reservoir by a contactless seal 16, such as a gas seal formed by gas, e.g. nitrogen, argon, helium or similar that do not readily dissolve into the liquid, provided under pressure to the gap between the seal member 17 and the substrate W. Between the seal member 17 and the projection lens PL, the liquid is confined by sealing members 14, optionally to keep the liquid pressurized. Alternatively, the sealing members 14 may be omitted and the liquid confined by gravity.

[0040] The bubble reduction means 3 can comprise bubble removal means. Figure 4 shows an aspect of the bubble removal means, wherein the liquid is made to flow continuously past the projection lens PL and substrate W. This action is particularly effective for transporting away bubbles from gas originating within the reservoir 13, e.g. those arising due to out-gassing from the substrate W. Liquid is introduced to the reservoir 13 through channels 23 formed at least partly in the seal member 17. These channels 23 may cooperate with channels for feeding the contact-less seal 16, which may consist of inlet and outlet ports for gas and/or liquid.

For example, liquid may be sucked from the region of the reservoir nearest the contact-less seal 16 by a gas outlet port and arranged to feed the continuous flow.

[0041] The bubble reduction means 3 can comprise bubble detection means 4. Figure 5 shows two arrangements of ultrasonic transducers 5a/5b in the bubble detection means 4. The principle of detection used here is that the ultrasonic wave amplitude will be attenuated due to Rayleigh scattering from bubbles in the liquid. The ultrasonic attenuation is a function of the size distribution and the number density of bubbles (*i.e.* the number per unit volume). In the left diagram, an ultrasonic transducer emits a pulse that, after passing through the immersion liquid and reflecting from a boundary within the reservoir (whether reservoir 13 or some other reservoir, for example exterior to the imaging axis), is received by the same transducer 5a. This arrangement of transducer 5a is known as a "pulse-echo" arrangement. The pulse-echo arrangement is effective because it only requires a single transducer 5a and it is relatively easy to have a large propagation path between emission and detection thus helping to maximize the sensitivity to bubbles. However, it is possible that anomalous reflections occur causing loss of signal. The sampling rate may also be limited by the fact that it is necessary to wait for the return of a pulse before emitting a further pulse. Arranging the transducer 5a so that it can emit and receive concurrently may obviate this problem. An alternative arrangement is shown on the right of Figure 5, using two transducers 5b each dedicated to either emitting or receiving ultrasonic waves. Here it is possible to emit rapid trains of pulses and the arrangement does not suffer from anomalous reflection effects since the wave pulses travel directly between the transducers 5b.

[0042] The attenuation is measured as a function of frequency in order to detect bubbles that are much smaller than the wavelength of the ultrasonic signals. This may be done using broadband transducers and excitations. Measuring attenuation at only a single frequency restricts detection to bubbles with diameters of the same order of size as or larger than the wavelength of the ultrasonic signals.

[0043] Figure 6 shows a further aspect of the bubble removal means according to an embodiment of the invention, wherein two ultrasonic transducers 5c powered by a signal generator 9 and phase shifted relative to each other by phase adjusting means 8 are arranged to produce a standing wave pattern 6 in the liquid between the faces of the transducers 5c. Figure 6 shows a standing wave made up of interfering sine waves but the standing waves may be of any periodic form (*e.g* square-wave or saw-tooth). The upper diagram represents the arrangement at a first instant and the lower diagram the same arrangement at a later instant. Bubbles present in the liquid (*e.g.* 2) tend to become localized near the nodal regions 7 of the standing wave 6. The phase adjusting means 8 act to shift the positions of the nodes towards one or the other of the two ultrasonic transducers 5c as shown by arrow 25. The trapped bubbles 2 move along with the moving nodes towards the transducer 5c in question and are therefore transported to an edge of a liquid reservoir. In Figure 6, this movement is to the left as indicated by the arrow 26 and the displacement of the sample trapped bubble 2 indicated by the displaced vertical broken lines that pass through the center of the trapped bubble 2 at the two consecutive times. Once a certain concentration of bubbles has accumulated near one transducer 5c, the liquid in this region may be isolated and removed from the reservoir, carrying the bubbles with it.

[0044] Figure 7 shows the degassing device 10 of the bubble removal means according to an embodiment of the invention. The degassing device 10 comprises an isolation chamber 11, which contains the liquid to be degassed. The degassing device 10 may further comprise a pump 12 arranged to extract gases from the isolation chamber 11 and, eventually, to achieve a low pressure state therein. The minimum pressure is preferably chosen to be greater than the saturated vapour pressure of the liquid being used so as to prevent boiling, e.g. around 23 mbar for water at room temperature. Once under reduced pressure, gases dissolved in the liquid will leave solution and be pumped away by the pump 12. Raising the temperature of the liquid can assist this process. For example, working between 40 and 50 °C typically increases the degassing speed by about a factor of ten. When the degassing process is complete, *i. e.* when no further dissolved gas can be extracted from the liquid, the isolation chamber 11 may be isolated by closing doors 15 located above the liquid. The liquid should remain isolated from the atmosphere until it is transferred into the reservoir 13 for use. The liquid may be kept either under vacuum or under a gas that will not easily dissolve into the liquid, such as nitrogen, argon or helium.

[0045] Figure 8 shows a liquid pressurization device 22 that acts to pressurize the reservoir liquid above atmospheric pressure according to an embodiment of the invention. High pressure has the effect of minimizing the size of bubbles and encouraging bubbles to dissolve into the liquid. The apparatus shown in Figure 8 consists of a piston 19 and a bore 21. Pushing the piston into the bore pressurizes the liquid. At its lower end, a valve 18 is provided to allow transfer of the liquid, for example into the liquid supply system 1. For monitoring purposes, a pressure gauge 20 is provided which may include a safety blow-off valve.

[0046] The bubble reduction means 3 may comprise elements both within the reservoir 13, as shown in Figure 4, and outside the reservoir 13 - see 3 a and 3b respectively in Figure 4. An advantage of having elements outside the exposure space 13 is that engineering considerations, such as the amount of space available or the allowable levels of vibrations and heat dissipation, are significantly relaxed. This fact not only makes it

cheaper to design processing elements but also opens the possibility for bulk processing. Such bulk processing may allow a single station to prepare liquid for use in a number of lithographic apparatuses or to provide a large quantity of conditioned liquid for use in a system where there is a continual throughput of liquid, or in a system where the liquid is changed on a frequent basis.

[0047] Bubble reduction means 3 located within the reservoir 13 are particularly effective for dealing with bubbles that unavoidably originate within the reservoir 13, such as from out-gassing.

[0048] The composition of the liquid may be chosen to have a lower surface tension than water. This reduces the tendency of bubbles to stick to the substrate (particularly acute for small bubbles) where they may be particularly damaging to the image and where they tend to be resistant to removal measures. This may be achieved by choosing a pure liquid with a lower surface tension or by adding a component to the liquid that reduces its surface tension, such as a surfactant.

[0049] Whilst specific embodiments of the invention have been described above, it will be appreciated that the invention may be practiced otherwise than as described. The description is not intended to limit the invention.

Claims

1. A lithographic projection apparatus comprising:

   - a radiation system for providing a projection beam of radiation;
   - a support structure for supporting patterning means, the patterning means serving to pattern the projection beam according to a desired pattern;
   - a substrate table for holding a substrate;
   - a projection system for projecting the patterned beam onto a target portion of the substrate;
   - a liquid supply system for at least partly filling a space between the final element of said projection system and said substrate with liquid,

   characterized in that said liquid supply system comprises bubble reduction means.

2. A lithographic projection apparatus according to claim 1, wherein said bubble reduction means comprise bubble detection means.

3. A lithographic projection apparatus according to claim 2, wherein said bubble detection means comprise at least one ultrasonic transducer, the attenuation of ultrasonic waves in said liquid being measured by said transducer so as to obtain information about bubbles present in said liquid.

4. A lithographic projection apparatus according to claim 3 wherein said ultrasonic transducer measures ultrasonic attenuation as a function of frequency.

5. A lithographic projection apparatus according to any one of the preceding claims, wherein said bubble reduction means comprise bubble removal means.

6. A lithographic projection apparatus according to claim 5, wherein said bubble removal means comprise a degassing device, said degassing device comprising an isolation chamber, wherein a space above liquid in said isolation chamber is maintained at a pressure below atmospheric pressure encouraging previously dissolved gases to come out of solution and be pumped away.

7. A lithographic projection apparatus according to claim 5 or 6, wherein said bubble removal means provides a continuous flow of liquid over the final element of said projection system and said substrate to transport bubbles in said liquid out of said space between the final element of said projection system and said substrate.

8. A lithographic projection apparatus according to any one of the preceding claims, wherein said bubble reduction means comprise a liquid pressurization device to pressurize said liquid above atmospheric pressure to minimize the size of bubbles and encourage bubble-forming gases to dissolve into said liquid.

9. A lithographic projection apparatus according to any one of the preceding claims, wherein the composition of said liquid is chosen to have a lower surface tension than water.

10. A lithographic projection apparatus according to any one of claims 1 to 9, wherein said bubble reduction means treat said liquid before it is supplied to said space between the final element of said projection system and said substrate.

11. A lithographic projection apparatus according to claim 10, wherein the treated liquid is kept in a sealed container, excess space in said sealed container being filled with one or more of the following: nitrogen gas, argon gas, helium gas or a vacuum.

12. A lithographic projection apparatus according to claim 3 or 4, wherein an ultrasonic transducer is arranged in a pulse-echo configuration, said transducer acting both to transmit ultrasonic waves and, after reflection, to receive ultrasonic waves that have been attenuated during propagation along a

path through said liquid.

13. A lithographic projection apparatus according to claim 3 or 4, wherein said bubble detection means comprise two spatially separated ultrasonic transducers, the first arranged to transmit ultrasonic waves, and the second to receive ultrasonic waves that have been attenuated during propagation along a path through said liquid between the two transducers.

14. A lithographic projection apparatus according to claim 5, wherein said bubble removal means includes two spatially separated ultrasonic transducers, arranged to produce ultrasonic standing-wave patterns within said liquid which trap bubbles within the nodal regions, said bubble removal means being arranged to displace said bubbles through the use of phase-adjusting means linked with said transducers, said phase-adjusting means causing spatial shift of nodal regions and bubbles trapped therein.

15. A device manufacturing method comprising the steps of:

- providing a substrate that is at least partially covered by a layer o f radiation-sensitive material;
- providing a projection beam of radiation using a radiation system;
- using patterning means to endow the projection beam with a pattern in its cross-section;
- projecting the patterned beam of radiation onto a target portion of the layer of radiation-sensitive material;
- a liquid supply system for at least partly filling a space between the final element of said projection system and said substrate with liquid,

characterized by the step of reducing bubbles in said liquid supply system.

Fig. 1

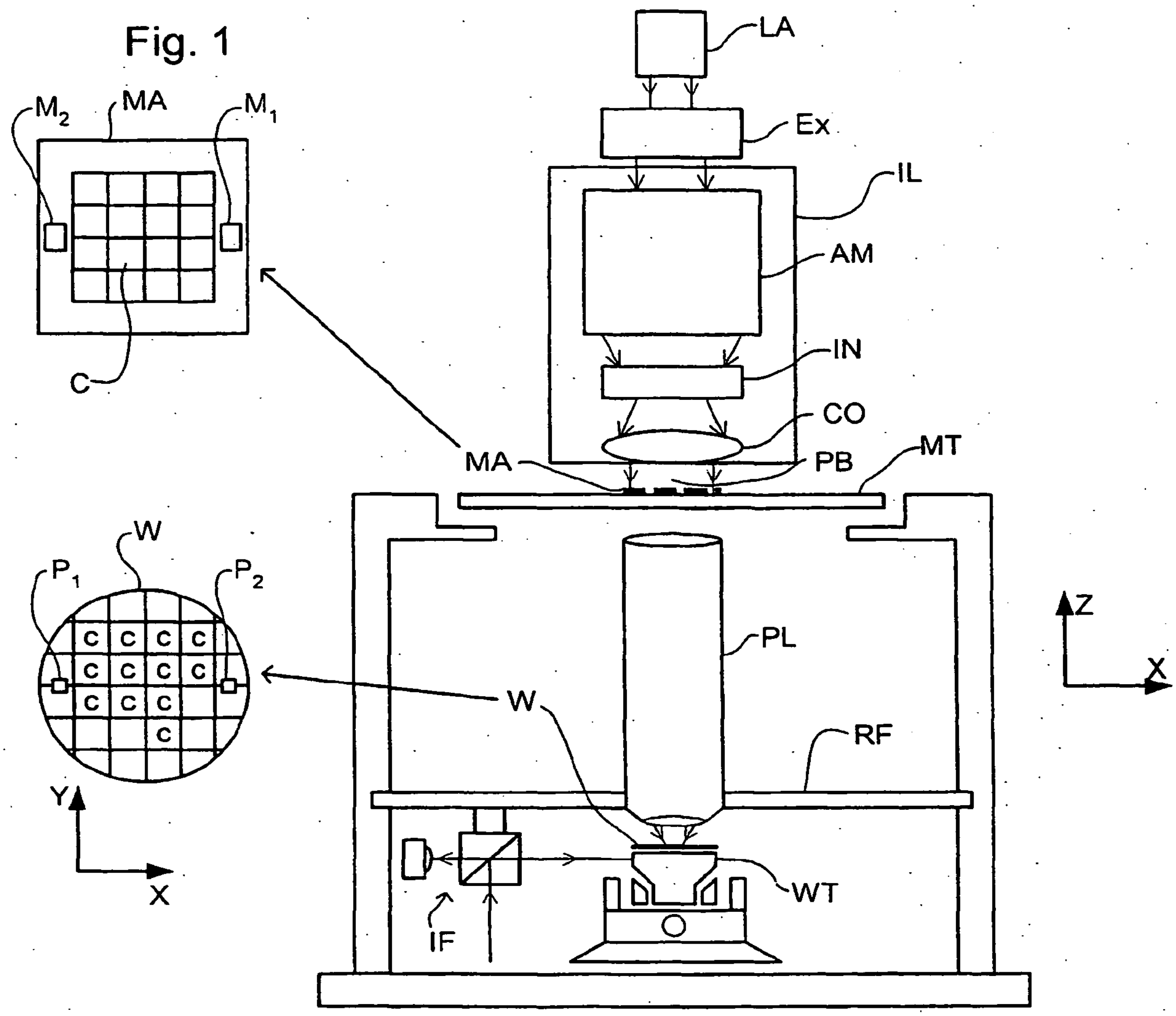

M2
MA
M1
C
W
P1
P2
c c c c
c c c c
c c c
c
Y
X
LA
Ex
IL
AM
IN
CO
MA
PB
MT
PL
W
RF
WT
IF
Z
X

Fig. 2

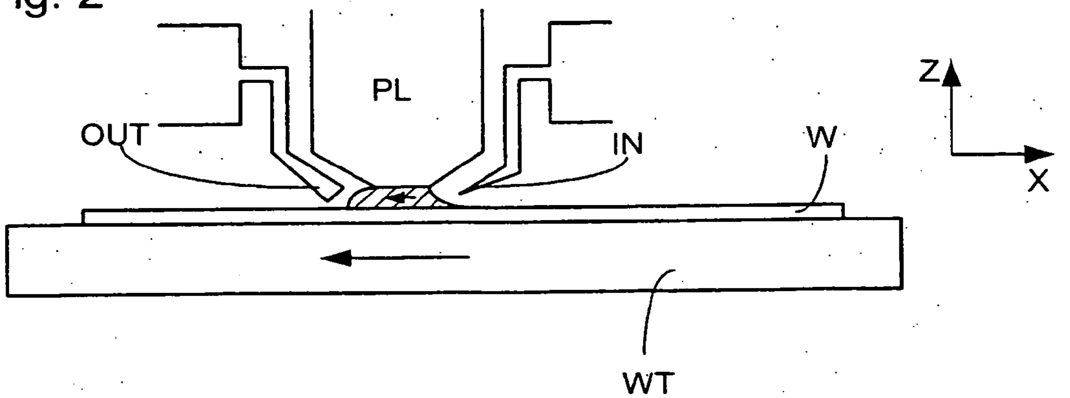


Fig. 3

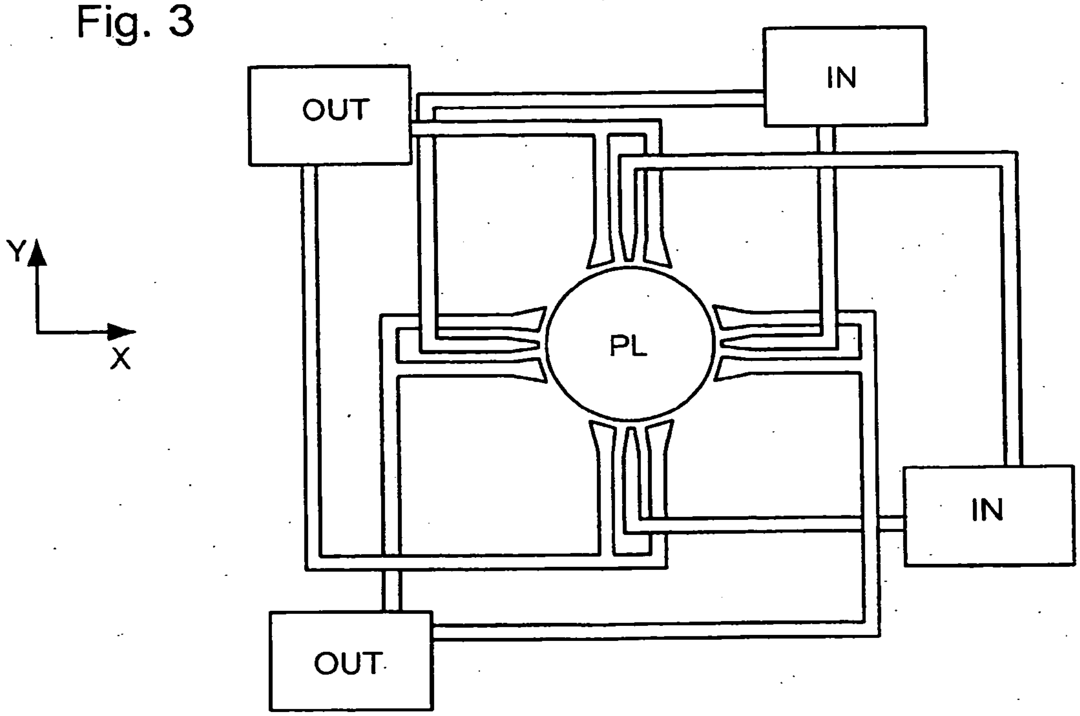


Fig. 4

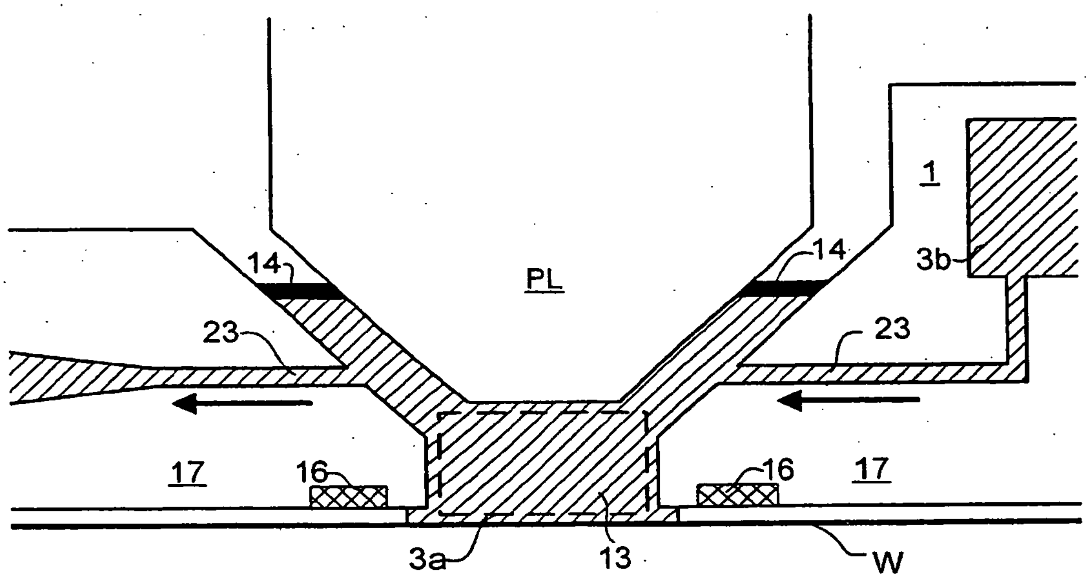


Fig. 5

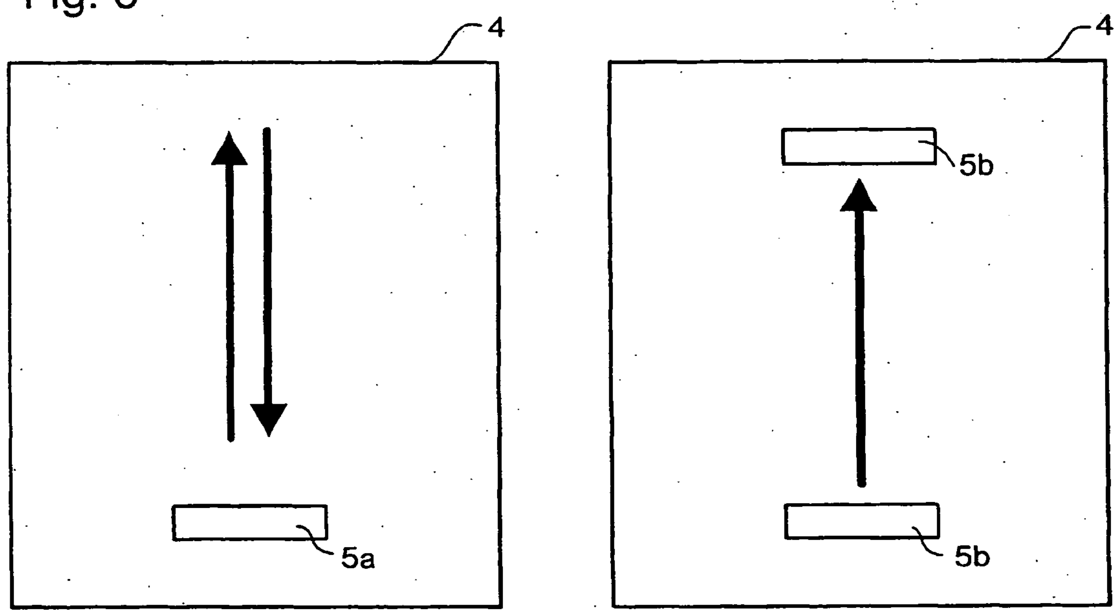


Fig. 6

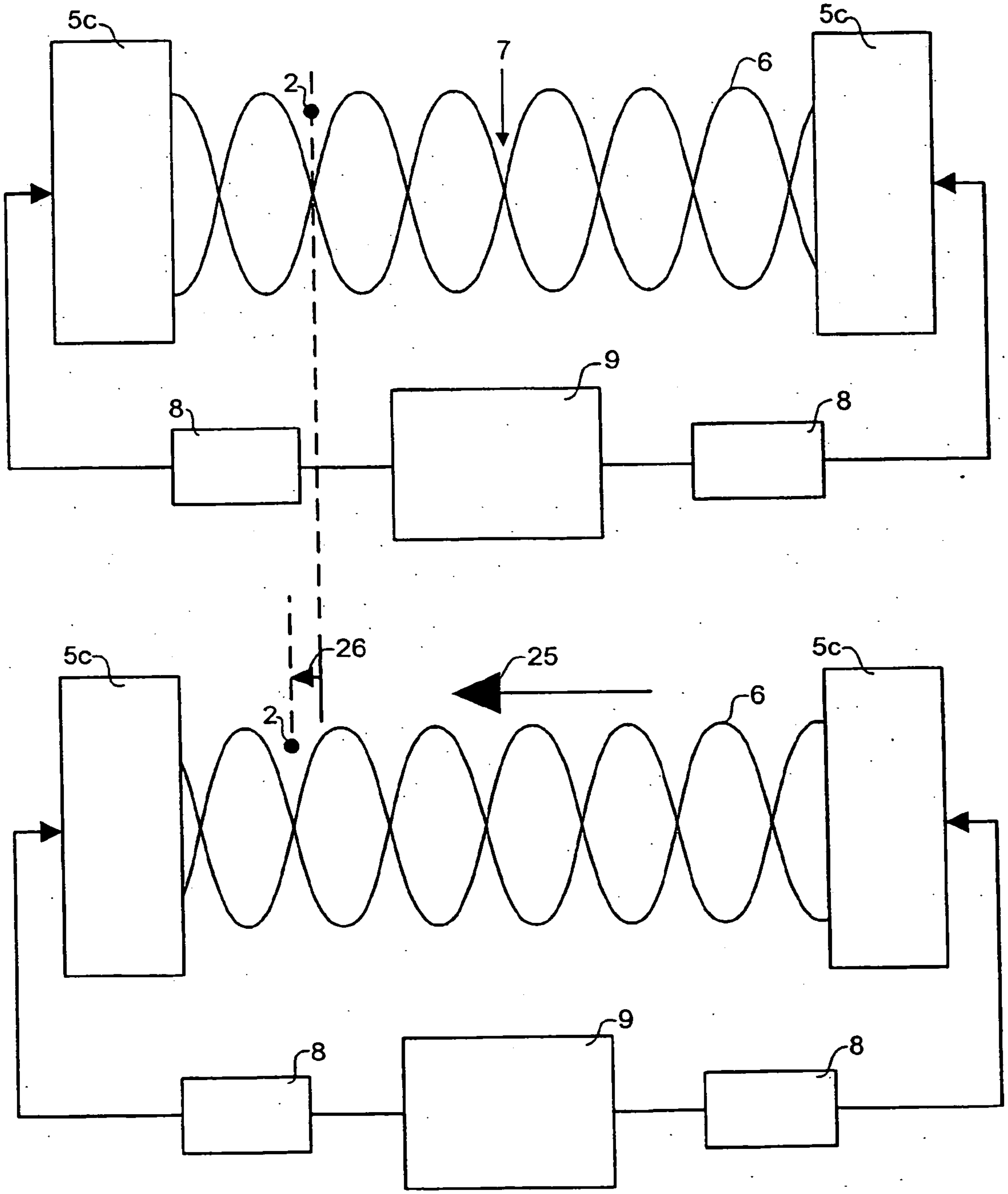


Fig. 7

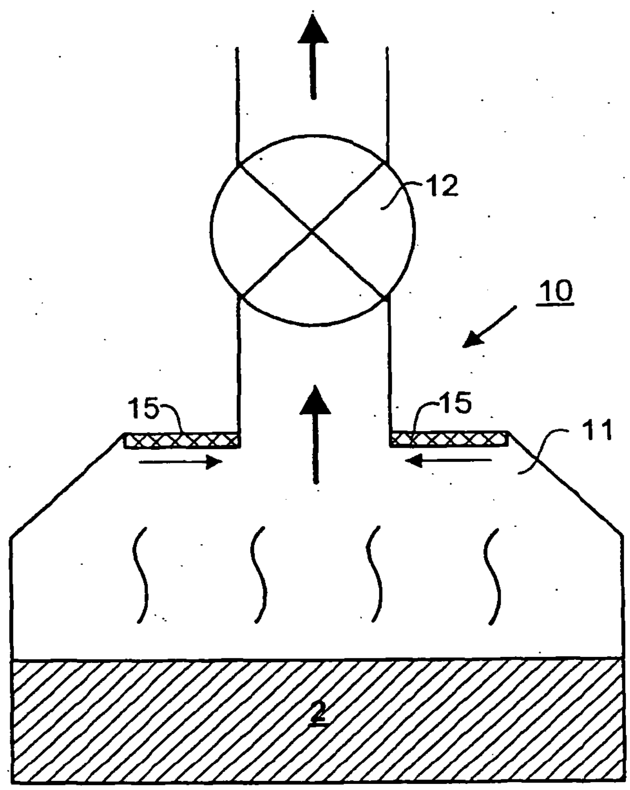
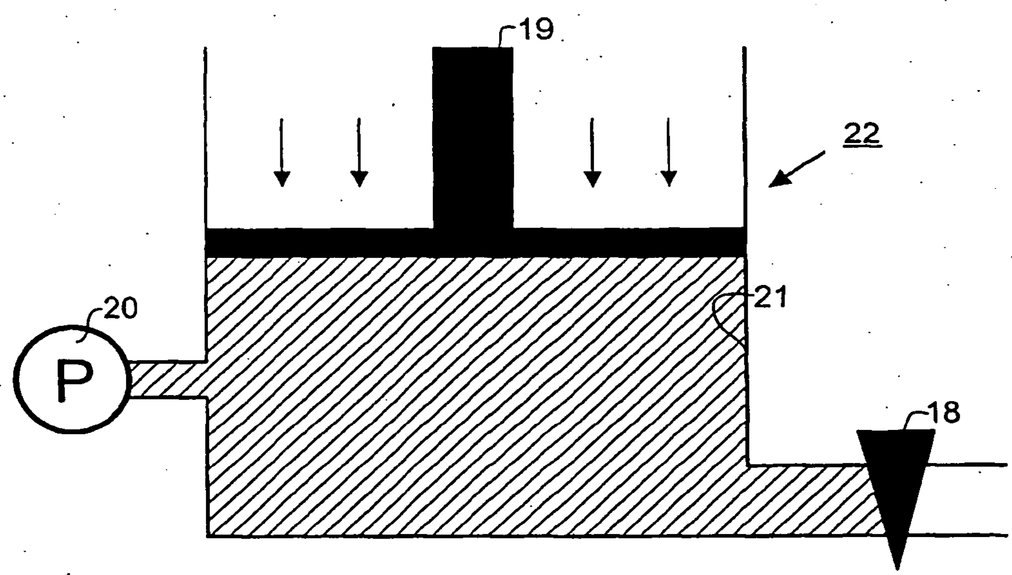


Fig. 8



European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 03 25 3694

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
X	EP 0 605 103 A (CANON KK) 6 July 1994 (1994-07-06) * column 5, line 41 - column 10, line 8 * * column 10, line 46 - column 11, line 49 * * figures 1,2,8 *	1,2,5,6	G03F7/20
X,D	US 4 509 852 A (LOEBACH ERNST W ET AL) 9 April 1985 (1985-04-09) * column 3, line 64 - column 4, line 35 *	1,5,7	
X	PATENT ABSTRACTS OF JAPAN vol. 1999, no. 02, 26 February 1999 (1999-02-26) & JP 10 303114 A (NIKON CORP), 13 November 1998 (1998-11-13) * abstract *	1,9	
A	US 5 900 354 A (BATCHELDER JOHN SAMUEL) 4 May 1999 (1999-05-04) * column 3, line 13 - column 4, line 42 * * column 5, line 40 - column 7, line 16 * * figure 2 *	1	TECHNICAL FIELDS SEARCHED (Int.Cl.7) G03F
A,D	WO 99 49504 A (FUKAMI YOSHIO ;MAGOME NOBUTAKA (JP); NIPPON KOGAKU KK (JP)) 30 September 1999 (1999-09-30) * abstract * * figures *	1	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	23 March 2004	Aguilar, M.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 03 25 3694

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

23-03-2004

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
EP 0605103	A	06-07-1994	JP	2753930	B2	20-05-1998
			JP	6168866	A	14-06-1994
			DE	69321571	D1	19-11-1998
			DE	69321571	T2	08-04-1999
			EP	0605103	A1	06-07-1994
			US	5610683	A	11-03-1997
US 4509852	A	09-04-1985	US	4346164	A	24-08-1982
JP 10303114	A	13-11-1998	NONE			
US 5900354	A	04-05-1999	WO	9901797	A1	14-01-1999
WO 9949504	A	30-09-1999	AU	2747999	A	18-10-1999
			WO	9949504	A1	30-09-1999

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82